Chapter 2

Environmental Assessment of Small Arms Live Firing: Study of Gaseous and Particulate Residues

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Small arms training is an important military activity of the Canadian Forces and the U.S. Army, and contributes to the accumulation of residues on the training areas. In the present work, the amount of unburned energetic residues deposited per round was estimated for five calibers (9 mm, 7.62 mm, 5.56 mm, 0.50 and 0.338) and nine weapons (Browning and Sig Sauer pistols, rifle C7, carbine C8, machine guns C6, C9 and M2HB, and rifles McMillan and Timberwolf). Samples were collected in aluminum containers located on the soil in front of weapons, and three air samples were collected using pumps, monitoring cassettes and sorbent tubes. The percentage of unburned Nitroglycerin (NG) per round varied between 0.001% and 3.90%, and up to 2.03 mg NG per round was deposited. Detectable concentrations of cyanide and acrolein were found in the gaseous emissions of 7.62- and 5.56-mm cartridges. Most particles collected during air sampling were smaller than 1 μm and made mainly of lead or copper. It is important to note that the reported concentrations are not representative of the soldiers' exposure because the sample was not collected in the breathing zone. These results indicate that the burning efficiency of most small arms is better than mortars, but worse than some artillery rounds, and that the accumulation of NG

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in the environment is cumulative over years, and probably decades.

Introduction

The small arms (SA) training represents a huge portion of military activities, since all service personnel must be qualified in the handling of a personal weapon. In this context, SA training ranges are being used extensively, which contributes to the escalation of residue accumulation on site. It is well known that heavy metals such as lead, copper, zinc and antimony accumulate in and near the stop berms in concentrations high enough to affect the soil, biomass, surface water, or even groundwater (*1*, *2*).

A large number of small arms ranges have been characterized in Canada and the United States to assess propellant residue accumulation in near-surface soils at firing point areas. Jenkins et al. (*3*) have shown that residues coming from the incomplete combustion of gun propellant accumulate as solid particulates in front of the firing positions of SA ranges. Major constituents of concern are 2,4-dinitrotoluene (2,4-DNT) and nitroglycerin (NG), which are part of single and double base propellants, respectively.

However, little is known about the amount and distribution of residues emitted per types of rounds and weapons, or about the parameters controlling the combustion of gun propellant in small arms. The combustion efficiency is thought to be influenced by the type of calibrer propellant and weapon used, as well as weather conditions. However, from range characterization data, the evaluation of the extent of contamination associated with a specific ammunition/weapon system is impossible. Indeed, none of these ranges is used for a single munition, and information on the historic use of a range is limited and sometimes inaccurate. Moreover, the soil of these ranges is often contaminated from unknown past activities. Not only is there a lack of information on the build-up of propellant residues on the ground, but also there is little information on the gaseous emissions resulting from the live-fire of the weapons. There is a need to better understand the gun propellant combustion and the parameters having an influence on the propellant efficiency.

In addition, the firing of a weapon produces an aerial plume composed of various gases and particles. Previous work was conducted in the United States by the U.S. Army Environmental Center to develop emission factors based on firing point emissions for various types of range operations, such as weapons firing, smoke and pyrotechnic devices, and exploding ordnances. The work, conducted with the United States Environmental Protection Agency (U.S. EPA), used different munitions test facilities, such as test chambers, blast spheres and bangboxes at the Aberdeen Test Center, Maryland, to sample and analyze emitted products. The results of theses tests led to the calculation of emission factors that were published in the U.S. EPA Compilation of Air Pollutant Emission Factors (AP-42) (*4*). An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed

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as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per megagram of coal burned). However, little is known about the composition of the aerial plume and the particulate matter that can stay in suspension several minutes around the shooter of a small arms weapon.

This study had two objectives. The first was to characterize the behaviour of various types of small calibre weapons and ammunitions and the distribution of gun propellant residues on the training range using the most common weapons under realistic training conditions. The second objective was to assess the nature of gaseous species and characterize solid particles emitted in the vicinity of the gun during the live firings.

Materials and Methods

A study was thus undertaken to estimate the amount of unburned energetic residues deposited per round fired. As shown in Table 1, five calibers (9 mm, 7.62 mm, 5.56 mm, 0.50 and 0.338) and nine weapons (Browning and Sig Sauer pistols, rifle C7, carbine C8, machine guns C6, C9 and M2HB, and rifles McMillan and Timberwolf) were selected for this study. A more thorough description of the weapons and ammunition can be found in Faucher et al. (*5*). Weapons were fired remotely from a fixed mount.

Several trials were done in duplicate and one was done in triplicate. Some trials could not be performed more than once because of operational time constraints. For all trials, samples were collected in aluminum containers strategically located on the ground in front of the gun. Air samples were also collected for three ammunition/weapons systems, commonly used in the Canadian Forces, using an enclosure bag when possible to minimize dilution. All samples were analyzed for NG and 2,4-DNT. In addition, gas samples were analyzed for polycyclic aromatic hydrocarbons (PAH), total cyanides, the BTEX suite (benzene, toluene, ethylbenzene and xylenes), aldehydes, and nitric acid.

Propellant Residues

Aluminum containers (Set-up is in Figure 1) were used to collect propellant residues. The sampling area was based on the results of Walsh *et al*. (*6*) for similar trials on snow. The calculations are based on the assumption that 100% of the plume was contained within the sampled area. Solvent was put in the containers to prevent any loss of particles. After a test, the contents of all particle traps at the same distance from the weapon were combined in a single sample. Propellant residues were extracted and analyzed by an in-house HPLC method derived from the current EPA analysis Method 8330b (*7*). One result of NG concentration (or mass) is thus obtained for each of the selected distances from the gun (1, 2, 3, 4, 5, 7.5, 10, 12.5, 15, 20 and 25 m). Then, a piece-wise linear concentration distribution was integrated in the axial direction to give the total mass of NG. The complete sample processing and calculations are reported in Faucher et al. (*5*).

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Table 1. Description of ammunitions and weapons used for each trial.

Ammunition		*Weapon*			
Cartridge	*Type*	*Type*	*Max Weapon Length cm*	*Max Barrel Length cm*	*Muzzle Velocity m/s*
9 mm	MK1 ball Luger 115 FMJ Frangible	Browing pistol (*10*) Sig Sauer pistol (*11*)	19.7 17.8	12.4 9.8	365 357
7.62 mm	C21/C19 4B1T[1] Link C24 blank link	C6 Machine gun (*12*)	127	67	840
5.56 mm	C77 ball clip C77/C78 4B1T[1] Link C79A1 blank link Frangible	C7A1 Automatic rifle (*13*) C8 Automatic carbine (*14*) C9A1 Light machine gun (*15*)	103 84 104	51 40 53	915[2] 910[2] 962
.50 cal	M2/M17 4B1T[1] Link AAA750 Hodgdon H50BMG 225 gr	Browning heavy machine gun (*16*) McMillan rifle (*17*)	166 144	114 74	860 818
.338 cal	Lapua Magnum	Timberwolf (*18*)	125	66	823

[1] Sequence of 4 ball and 1 tracer in a link belt. [2] Velocity at 24 m.

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Figure 1. Stop berms and sampling layout.

Gases and Airborne Particles

Gases and airborne particles were sampled using sorbent tubes and filters for three weapons: 1) Browning pistol, 9 mm MK1 ball (500 rounds); 2) machine gun C6, 7.62 mm link C21/C19 ball (880 rounds) and; 3) automatic rifle C7, 5.56 mm C77 ball (450 rounds). As shown in Figure 2, the sampling media were strategically positioned at two locations: close to the muzzle of the gun and near the upper receiver. For the C6 machine gun and the C7 automatic rifle, an enclosure bag was placed around the gun in order to minimize the gas and particle dispersion. Details of sampling are reported in Faucher et al. (*5*). Sampling tubes were analyzed by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST, Montreal, Canada). Particle size distribution, morphology, and chemical composition were studied at Université Laval (Quebec, Canada) by scanning electron microscopy (SEM) with a JEOL JSM-840A microscope equipped with a NORAN energy dispersive X-ray spectrometer.

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Figure 2. Browning pistol surrounded by air-monitoring cassettes and sorbent tubes.

Results

Gun Propellant Residues

The dispersion of NG per calibreris shown in Figure 3. For simplicity of presentation, NG concentrations are reported in mg per 1000 rounds, per area sampled. Table 2 gives a summary for each ammunition/weapon. The results of NG dispersion show that most of the rounds and weapons that were tested deposited a mass of NG below 0.09 mg/round or that the percentage of unburned NG/round is lower than 0.06%. Exceptions are the following:

- Cartridges 9 mm, which deposited between 0.74 and 2.03 mg NG/round (1.39 to 3.90% of unburned NG per round). The dispersion seemed to be worse when the Sig Sauer pistol was used.
- Cartridges 7.62 mm, both C21/C19, ball, linked and C24, blank, linked, fired with the C6 machine gun, which were found to deposit approximately 0.98 and 0.16 mg NG per cartridge, corresponding to 0.3% (theoretical calculation) and 0.11% of unburned NG per round, respectively.
- Cartridges 5.56 mm, C77/C78, ball, fired with the C7 automatic rifle, that deposited 0.30 mg/round (0.19% of unburned NG per round).

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- Frangible cartridges 5.56 mm fired with the C7 automatic rifle, which led to an amount of 1.06 mg NG/round (0.62% of unburned NG per round).

The results indicate that cartridges 9 mm deposited a larger amount of unburned NG on the soil and had a lower burning efficiency. The burning efficiency seems to increase as the amount of propellant in the round increases, with the exception of cartridges 7.62 mm, for which more gun propellant residues were emitted for cartridges ball and blank, as compared to 5.56-mm cartridges. Blank cartridges had a burning efficiency similar to that of ball cartridges, but since less propellant was present, smaller amounts of NG (0.01-0.02 mg, as compared to 0.05-0.30 mg) were deposited per round fired.

The results also confirmed that either the weapon and/or the primer had a significant effect on the burning efficiency because very different values were obtained for the 9 mm fired with the same propellant (WPR 289), but using different pistols and primers (0.74 and 2.03 mg NG). The results for the frangible cartridges 9 mm and 5.56 mm should be verified in a subsequent study because the contamination associated with those two rounds was unusually high. These findings suggest that the lead-free primer may not be as effective as current formulations to ignite the gun propellant.

The cartridges 5.56 mm were fired with the same propellant (PRB SS 109), but using three weapons with different barrel lengths (C7, 67 cm; C8, 40 cm; C9, 52 cm); the precision of the results was not high enough because of the wind. It was not possible to see any clear tendency of the effect of the barrel length or firing mechanism. The calibrer.50 cartridge had a high burning efficiency, but because of the larger amount of propellant in the round, each shot deposited a larger amount of NG (0.25 mg) into the environment. And lastly, considering the large amount of propellant in the Lapua Magnum, the release of NG by the Timberwolf sniper rifle was quite small (0.03 mg) compared to the other small arms.

The percentages of unburned NG per round were within an order of magnitude to those of Walsh et al. (*6*, *8*), who obtained 1.1% of unburned NG for the cartridges 5.56 mm fired from a rifle (as opposed to 0.2-0.6% in this study), 0.56% for the cartridges 7.62 mm fired from a machine gun (as opposed to 1.36% in this study), 5.4% for the cartridges 9 mm (as compared to 1.39 to 3.90% in this study) and 0.73% for the calibre .50 cartridges (as compared to 0.02% in this study). Nevertheless, dispersion patterns for all of the rounds were similar.

A certain number of reasons can be invoked to explain the differences between the trials of Walsh et al. (*6*, *8*), and those of this study. One of them is certainly the trial set-up. Walsh's trial was conducted on snow, with the weapon located just high enough (approximately 30 cm) from the surface to minimize the effect of the muzzle blast. For our study, the trial was done in the spring, at temperatures approximately 30°C higher than those of Walsh; samples were recovered in aluminum containers filled with solvent, and weapons were much farther from the ground (1 m). The effect of the wind, which was more significant during some of our trials with the cartridges 5.56 mm and the calibrer.50 cartridges, cannot be ruled out. Another important point is that the Canadian and the U.S. Armed Forces do not use the same weapons, and often not the same gun propellants and primers. This could contribute to significant

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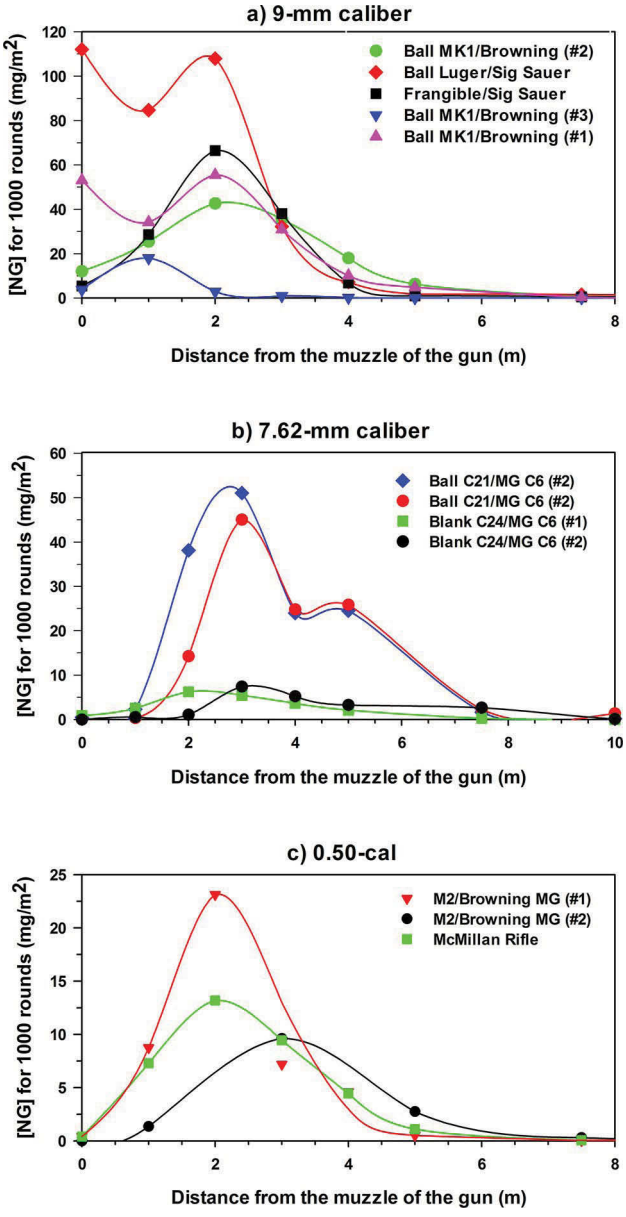
differences, as shown from our results for the cartridges 9 mm fired with Sig Sauer and a lead-free primer (2.03 mg NG, 3.90% of unburned NG) and the Browning pistol with a traditional primer (0.74 mg NG, 1.39% of unburned NG per round). Also, the manufacturer's data are often imprecise, inaccurate, or hard to obtain; in-house analysis of the gun propellant used for a given experiment should always be obtained to allow for more accurate estimates of burning efficiencies.



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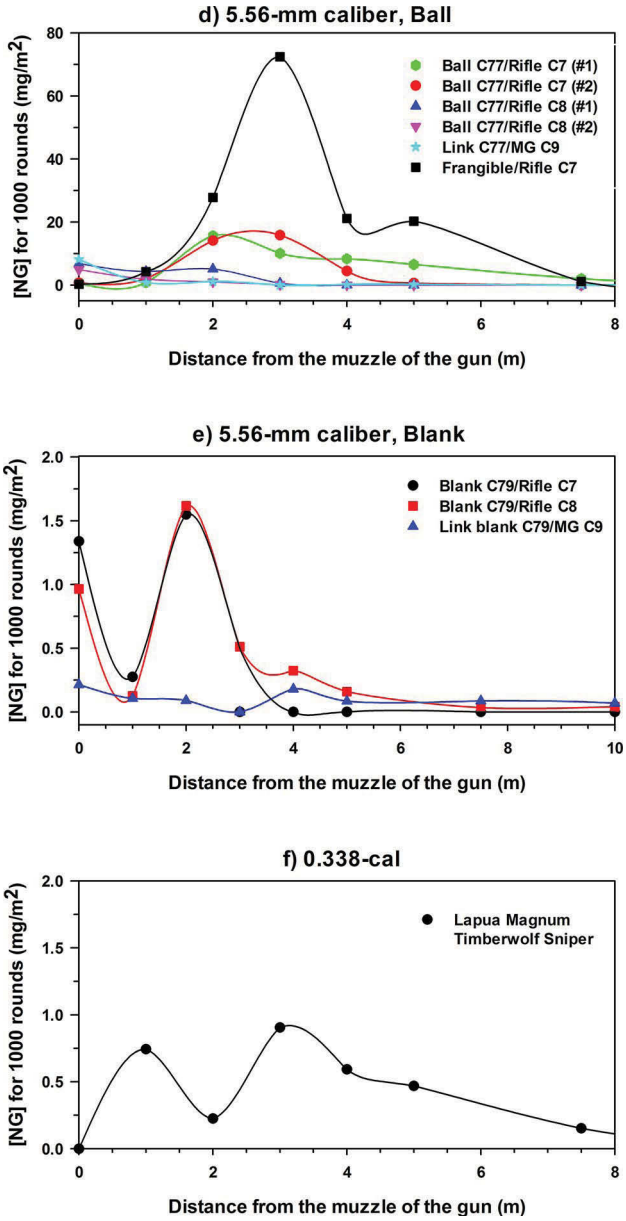

Figure 3. Dispersion of NG on the ground after 1000 rounds, a) 9-mm caliber, b) 7.62-mm caliber, c) 5.56-mm caliber, d) 0.50-cal, e) 0.338-cal. (see color insert)

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Table 2. NG residues per cartridge/weapon

Calibre	*Weapon*	*Cartridge*	*Propellant Type*[1]	*NG/round*	
				mg	*%*
9 mm	Browning pistol	MK1, ball	WPR 289	0.74	1.39
	Sig Sauer	Frangible	PCL 2595	0.95	1.97
	Sig Sauer	Luger 115 FMJ ball	WPR 289	2.03	3.90
7.62 mm	C6 Machine gun	C21/C19, 4B1T	WC 846	0.98	0.3[2]
	C6 Machine gun	C24, blank	Unique no. 20	0.16	0.11
5.56 mm	C7 Automatic rifle	Frangible	WC 747	1.06	0.62
	C7 Automatic rifle	C77, ball	PRB SS 109	0.30	0.19
	C7 Automatic rifle	C79A1, blank	NA	0.02	0.05
	C8 Automatic carbine	C77, ball	PRB SS 109	0.07	0.04
	C8 Automatic carbine	C79A1, blank	NA	0.02	0.06
	C9 Light machine gun	C77/C78, 4B1T	PRB SS 109	0.05	0.03
	C9 Light machine gun	C79A1, blank	XPRO-11GO	0.01	0.01
.50 cal	Browning machine gun	M2/M17, 4B1T	WC 860 (M2) IMR 5013 (M17)	0.25	0.02
	McMillan rifle	AAA750 Hodgdon H50BMG	NA	0.27	0.02
.338 cal	Sniper Rifle (Timberwolf)	Match B406	RP15/LAPUA	0.03	0.001

[1] NA: not available. [2] Based on a mean percentage of 10% NG in the C21 (*19*).

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Gas Residues

During combustion of the gun propellant, gases and particulate matter are produced at the gun muzzle and at the upper receiver. Gas analyses are shown in Table 3. Only a few of the selected gaseous compounds (polycyclic aromatic hydrocarbons, benzene, toluene, ethylbenzene, xylenes, total cyanides, nitrates, and aldehydes) were detected. For the 9-mm pistol, none of the selected gases were detected. In the case of the C6 machine gun, cyanide, acrolein, 2,4-DNT, and benzene were detected. A similar situation was observed for the C7 rifle: cyanide, acetaldehyde, and acrolein were detected.

Table 3. Gas analysis of air samples collected at the muzzle and the upper receiver of the gun

Weapon/cartridge	*Position*	*Compound detected*	*Concentration mg/m³*
Browning pistol 9 mm, MK1, ball	Muzzle of the gun	None	---
	Upper receiver	None	---
C6 Machine gun 7.62 mm, C21/C19, ball	Muzzle of the gun	Total cyanide	0.13
		Acrolein	0.002
		2,4-DNT	6×10^{-6}
	Upper receiver	Total cyanide	0.89
		Benzene	0.11
		Acrolein	0.004
C7 Automatic rifle 5.56 mm, C77, ball	Muzzle of the gun	None	---
	Upper receiver	Total cyanide	2.4
		Acetaldehyde	0.035
		Acrolein	0.023

Airborne Solid Residues

Monitoring cassettes with filters were inspected visually in order to make a qualitative evaluation of the particles collection. As seen in Figure 4a, the monitoring cassettes after the firing of the 500 cartridges 9 mm MK1 ball, with the Browning pistol have a very different appearance if they were positioned at the muzzle of the gun (Figure 4a, left) or at the upper receiver (Figure 4a, right). The filter at the muzzle of the gun is of light grey color while the filter at the upper receiver is still white. Obviously, the number of particles collected at the muzzle is higher. Figure 4b shows the monitoring cassettes after the firing of 800 7.62-mm cartridges, C21/C19, with the C6 machine gun, and Figure 4c shows the filters after the firing of 450 5.56-mm cartridges, C77, with the C7 automatic rifle. In both cases, the number of particles was higher at the upper receiver (cassettes

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on the right hand side) than at the muzzle of the gun (cassettes on the left hand side). The presence of the enclosure bag was certainly the cause of this efficient collection of particles. The lower number of particles for the 9-mm pistol trial can be explained by the absence of the enclosure bag, and also by the fact that the ammunition used contained a lower mass of propellant.

All of the filters from the monitoring cassettes located at the muzzle and at the upper receiver of the guns were analyzed by SEM. The results of all calibersare summarized in Table 4. Figures 5 and 6 show typical micrographs of particles obtained at the muzzle and the upper receiver for the calibrer9 mm. The analysis of the particles emitted from the cartridges 9 mm fired with the Browning Pistol indicate that lead was the main component of the particles smaller than 1 μm (both sampling positions). Most particles collected after the firing with the C6 were also smaller than 1 μm and composed of copper and lead. The particle analysis showed that copper was the main component of particles sampled near the muzzle, while at the upper receiver, it was lead. A similar situation was observed for the cartridges 5.56 mm C77 fired with the rifle C7.

Discussion

At first glance, the reported amounts of unburned NG per round can be seen as low, and the burning efficiency, pretty high. However, artillery rounds generally have higher burning efficiencies (0.0005 to 0.08% of unburned NG per bullet) than small arms (*6*); the burning efficiency of mortars (1.4 to 3.5% of unburned NG per round) is either similar to or lower than that of small arms. Moreover, the large number of bullets fired on small arms ranges has to be taken into account to evaluate the impact on the environment. For example, on a small arms range, on which were fired approximately 0.5M cartridges 5.56 mm (ball) per year since 1996, the calculated amount of NG deposited on the soil surface is 150 g per year. With the hypothesis that all of the rounds were fired from the 100-m berm to the 400-m berm in a 75 000-m^2 area, and using a soil density of 1.7 g/cm^3, the concentration of NG on the top 2-cm of surface soil should be approximately 0.06 mg/kg. Reported concentrations on the 100-yard firing berm were three orders of magnitude higher than those of Jenkins et al. (*3*), but they tended to decrease after 15 m. Nevertheless, none of the results went below 0.1 mg/kg up to 40 m in front of the firing point, and the mean NG concentration was 8.8 mg/kg. Instead, if Walsh's values of 1.1% per cartridge and a 1-cm sampling depth are used, the loading rate is 0.7 mg/kg/yr, which is closer but still lower than the reported concentrations of NG. Of course, other munitions were also fired on that range, but they amounted to less than 4% of the total number of rounds fired, including cartridges 7.62 mm (1.4%), cartridges 5.56 mm, linked (1.4%) and cartridges 9 mm (0.3%). The results thus tend to indicate that NG has a significant cumulative effect. However, care has to be taken when interpreting these soil surface characterization results because only 12% of the entire surface was sampled, and no depth sampling was done.

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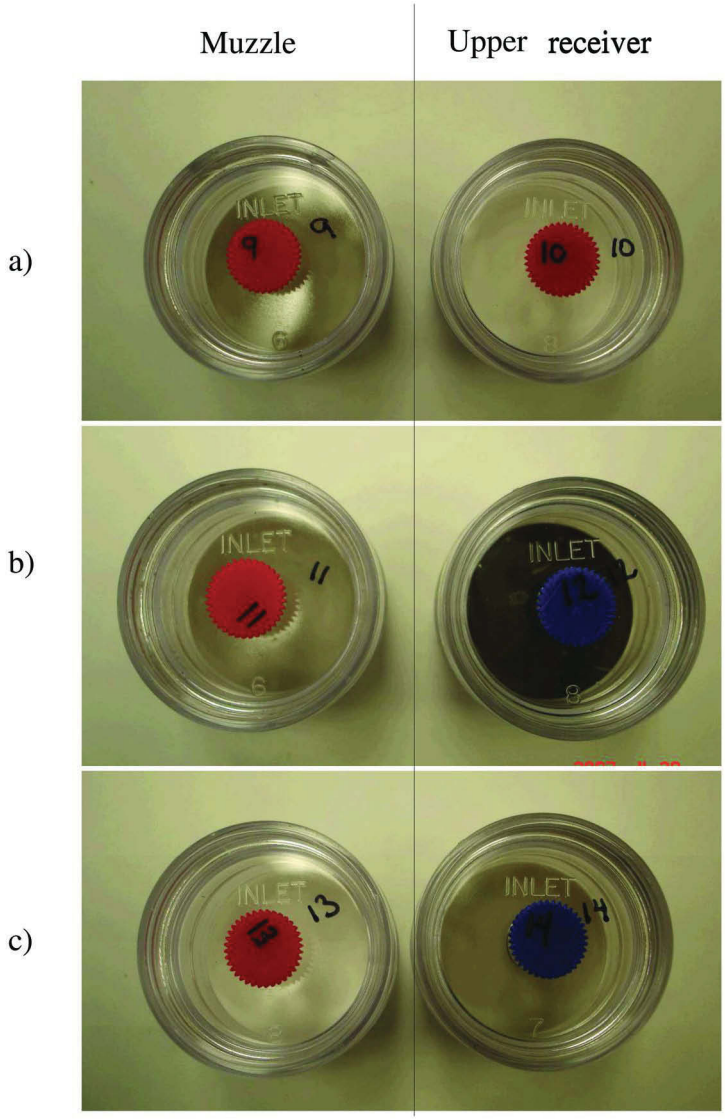

Figure 4. Monitoring cassettes (left: muzzle of the gun, right: upper receiver) a) After sampling 500 9-mm cartridges, MK1, ball, with the Browning pistol; b) After sampling 880 7.62-mm cartridges, C21/C19, ball, with the C6 machine gun; c) After sampling 450 5.56-mm cartridges, C77, ball, with the C7 automatic rifle. (see color insert)

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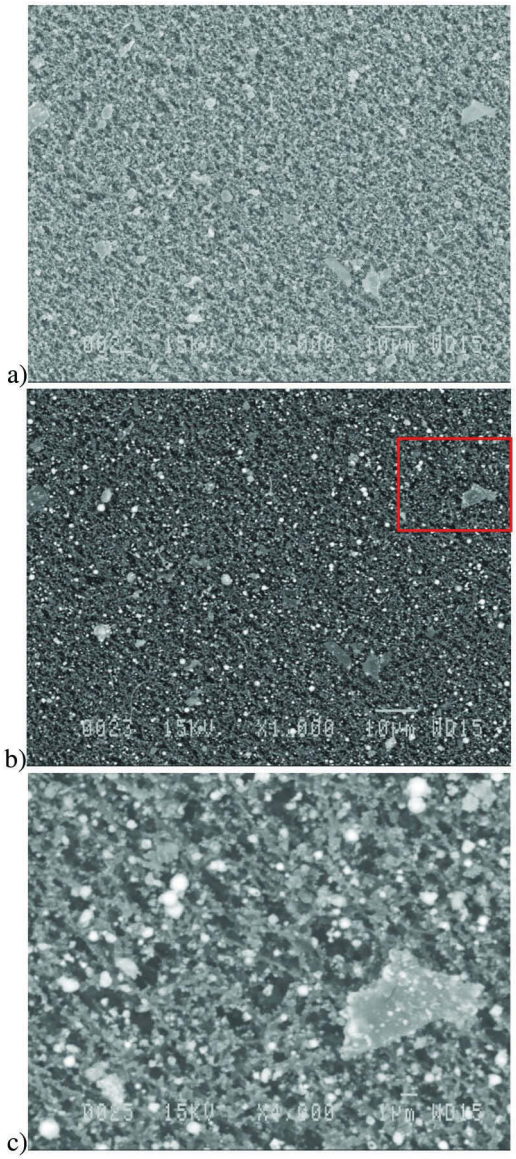

Figure 5. Micrographs of particles collected on filter #9 (muzzle of the 9-mm pistol); a) SE 1000x magnification, b) BEI 1000x, c) BEI 4000x, zoom of the red-squared region.

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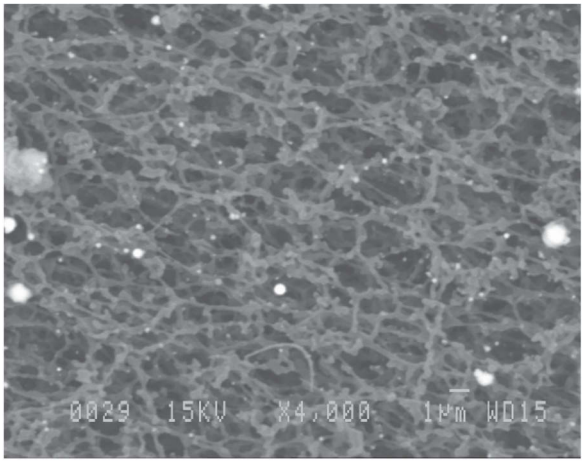

Figure 6. Micrograph of particles collected on filter #10 (upper receiver of the 9-mm pistol) (BEI 4000x magnification).

The same calculation was applied to another small arms range. This time, the entire surface of the range was sampled using the multi-increment approach as described in EPA Method 8330b (*7*) because of it small size (1250 m^2). The calculated loading from the amount of unburned NG per round using an average of 70,000 cartridges 9 mm fired each year led to a deposit of 52 g NG on the soil each year. However the estimated loading from surface soil characterization of the top 2cm gives an amount of NG that is slightly over 1 kg, which corresponds to a 20-year accumulation. This does not take into account the contaminants below the soil surface, because no depth profiling was done. So, either the amount of unburned NG per round is grossly underestimated, or there is a significant cumulative effect of NG in the environment. Although the amount of NG is certainly slightly underestimated, the long-term persistency of NG is not unexpected, because it is embedded in a nitrocellulose (NC) matrix, which is insoluble in water and does not degrade. NC can thus stay a very long time on the surface of the soil, and is probably trapping NG (*9*).

Another discrepancy between soil surface characterization and the results of this study is worth noting. Indeed, energetic residues were detected up to 40 m in front of the firing points, while in this study residues do not get farther than 12 m from the muzzle of the gun. Several hypotheses could explain this phenomenon. This could be the result of a multi-decade use that allowed the NG concentrations to build-up until high enough for detection. It could also be the result of runoff water carrying particles far from their ejection point, or be due to dominant wind that could blow in a direction that is parallel to the firing lanes. The hypothesis of soldiers firing between berms is considered improbable because this has not been the usual military practice for the last three decades, except for the 100-m berm. Older military practices are unknown.

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Table 4. Comparison of the particulate matter collected with the monitoring cassettes for different weapons/cartridges

Weapon/cartridge	*Sampling position*	*Proportion*	*Particle Size*	*Composition*	*Morphology*	*Source*
Browning Pistol #2, cartridges 9 mm, MK1, ball	Muzzle of the gun	Majority	< 3 µm, majority < 1 µm	Pb	Spherical	Pb: vaporization of the primer, followed by its solidification as small particles
		Minority	3-10 µm	C and Pb	Irregular and fractured (probably soot)	
	Upper receiver	Majority	≤ 1µm	Pb	Spherical	Pb: vaporization of the primer, followed by its solidification in small particles
Machine gun C6, cartridges 7.62 mm, C21, ball (weapon enclosure bag)	Muzzle of the gun	Majority	100 nm - 3 µm	Cu (+ traces of Sr and Pb)	Spherical	Cu: erosion of the cartridge inside the gun Sr: tracer composition
		Minority	5 µm	C and O	Flaky and irregular (probably soot)	Cu: erosion of the cartridge case inside the barrel of the gun
	Upper receiver	Majority	< 1 µm	Pb (+ traces of Sb, Cu, Ca, K, C and O)	Spherical	Sb and Pb: priming composition (Type C) Cu: erosion of the cartridge inside the gun K: propellant composition
		Minority	1-5 µm		Flaky and irregular	

In Environmental Chemistry of Explosives and Propellant Compounds in Soils and Marine Systems: Distributed Source Characterization and Remedial Technologies; Chappell, M., et al.; ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

The particle analysis for the three calibers under study showed that copper was the main component at the muzzle, while at the upper receiver, it was lead. It is not believed that the bullet can liberate any lead during its propulsion out of the gun because it is covered with a copper/zinc jacket. Rather, the main source for lead on the filters was probably the primer: lead was vaporized during the firing and was condensed shortly afterward in small particles. These particles may be carried by the winds, spreading lead in areas other than the firing point. This assumption has to be confirmed by further studies. At the upper receiver, particles collected are from the combustion of the primer. The main source of copper is probably the erosion of the cartridge inside the barrel. As these particles (created by the melting of the metal followed by its subsequent condensation on cooling), were following the trajectory of the bullet, it is normal that they are mainly ejected at the muzzle of the gun. The erosion of the cartridge seemed to become significant enough that particles of copper are found for longer barrels (C6 machine gun and C7 automatic rifle).

Conclusion

In this study, 23 trials were performed with 15 different calibers/weapons (including duplicate and triplicate), and three of them were air-sampled to measure selected airborne gases and particles. The results indicated that up to 2.03 mg NG/round was deposited. This makes the burning efficiency of most SA better than that of mortars, but less than that of artillery. Although the amount of dispersed NG per bullet seems low, the large amount of small calibre ammunition used in training can lead to significant accumulation on the surface of the soil, especially since SA ranges are small.

Only a few of the selected gaseous compounds were detected. Cyanide and acrolein were detected for both the 7.62- and 5.56-mm rounds. The use of an enclosure bag over the weapon improved the efficiency of particles and gases collection by reducing the dilution with the surrounding air, especially when winds were present. Most airborne particles collected were smaller than 1 μm and made of Pb (lead) and Cu (Copper). The concentrations reported are not representative of the soldier exposure since the sample collection was not made in the breathing zone.

The study of these results will lead to a better understanding of the burning mechanisms for a specific propellant under various conditions. This will help decision-makers in developing improved management tools for outdoor military training ranges.

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